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Biosignature Preservation and Detection in Mars Analog Environments

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Workshop information

- Conference on Biosignature Preservation and Detection in Mars Analog Environments held May 16th-18th, 2016 with 90 scientists at Incline Village, NV
- Workshop Objective:

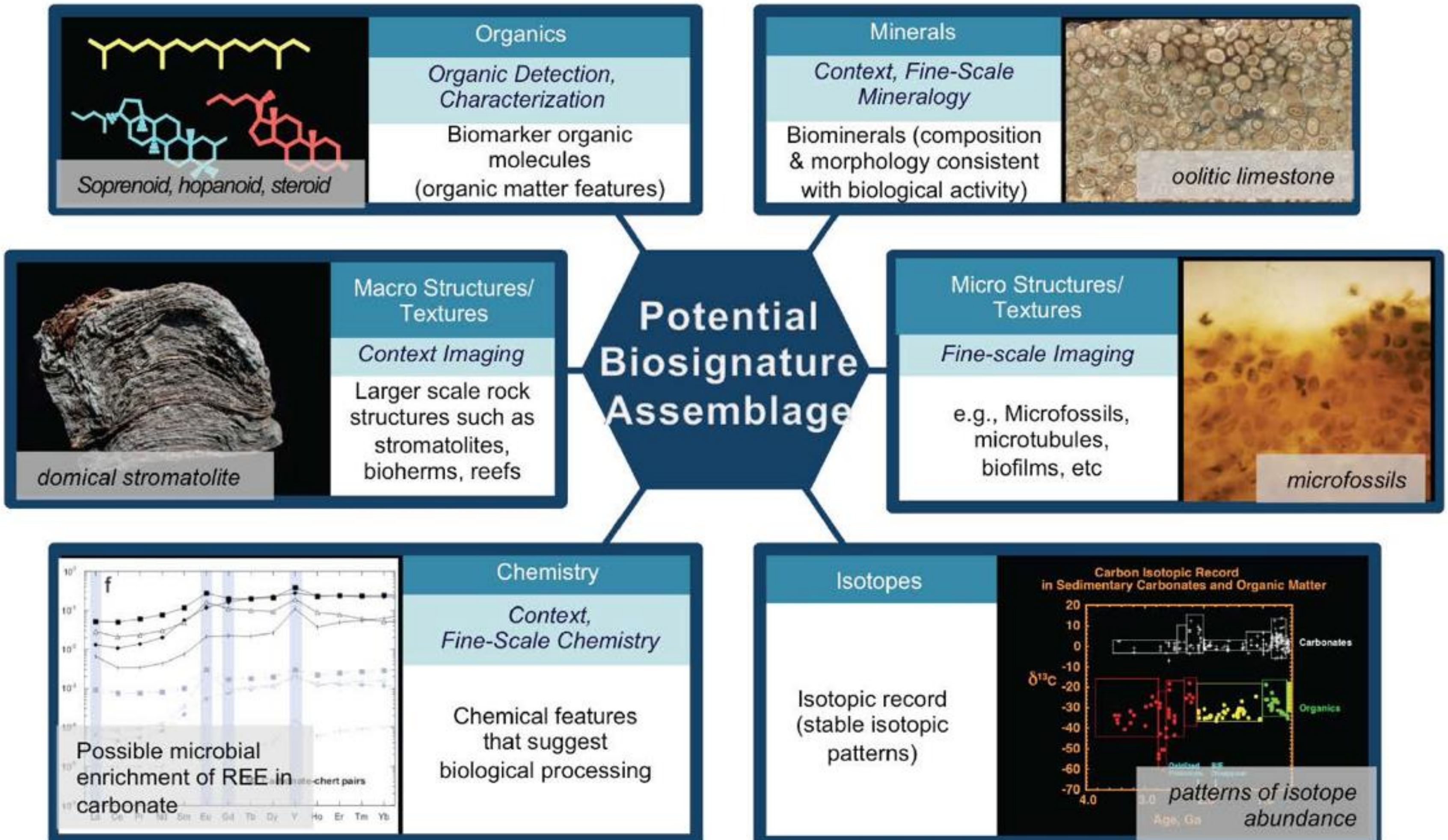
  Assess the attributes and the preservation potential of biosignatures in diverse Mars-analog habitable environments to develop strategies to detect a range of possible biosignatures on Mars.
- Workshop Output: Conference Report and Review Paper in *Astrobiology*

Landing Site Selection Criterion

Criterion 1: The site is an astrobiologically-relevant ancient environment with geologic diversity that has the potential to yield fundamental scientific discoveries when it is a) characterized for the processes that formed and modified the geologic record; and b) subjected to **astrobiologically-relevant investigations (e.g. habitability and biosignature preservation potential)**.

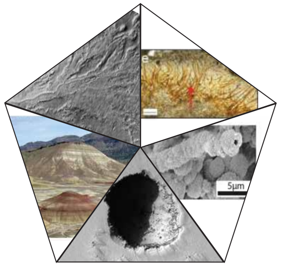
- How do we study what these will be like on Mars? Martian Analog Environments

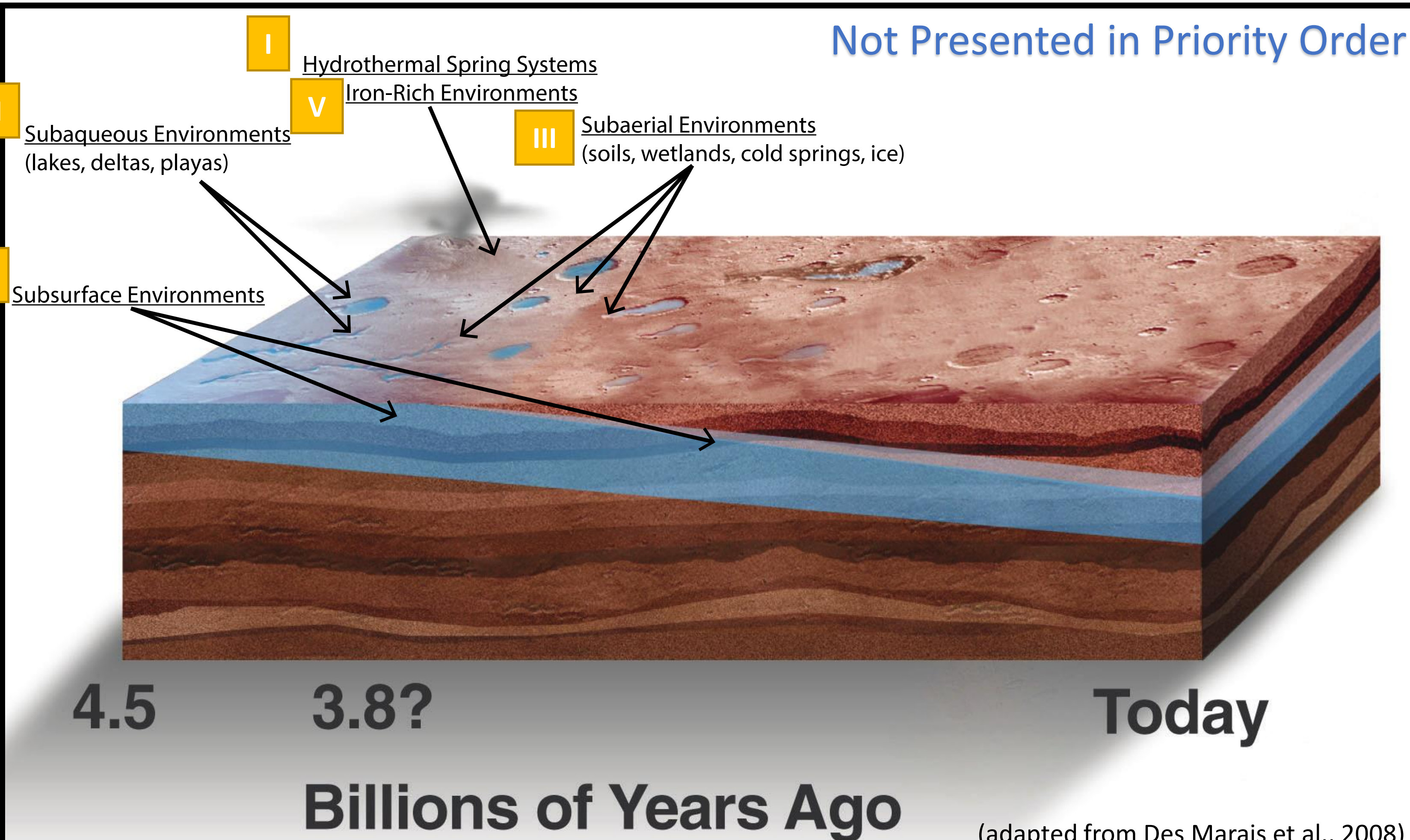
Six Classes of Biosignatures



(from Mustard et al. 2013)

Astrobiologially-Relevant Martian Analog Environments





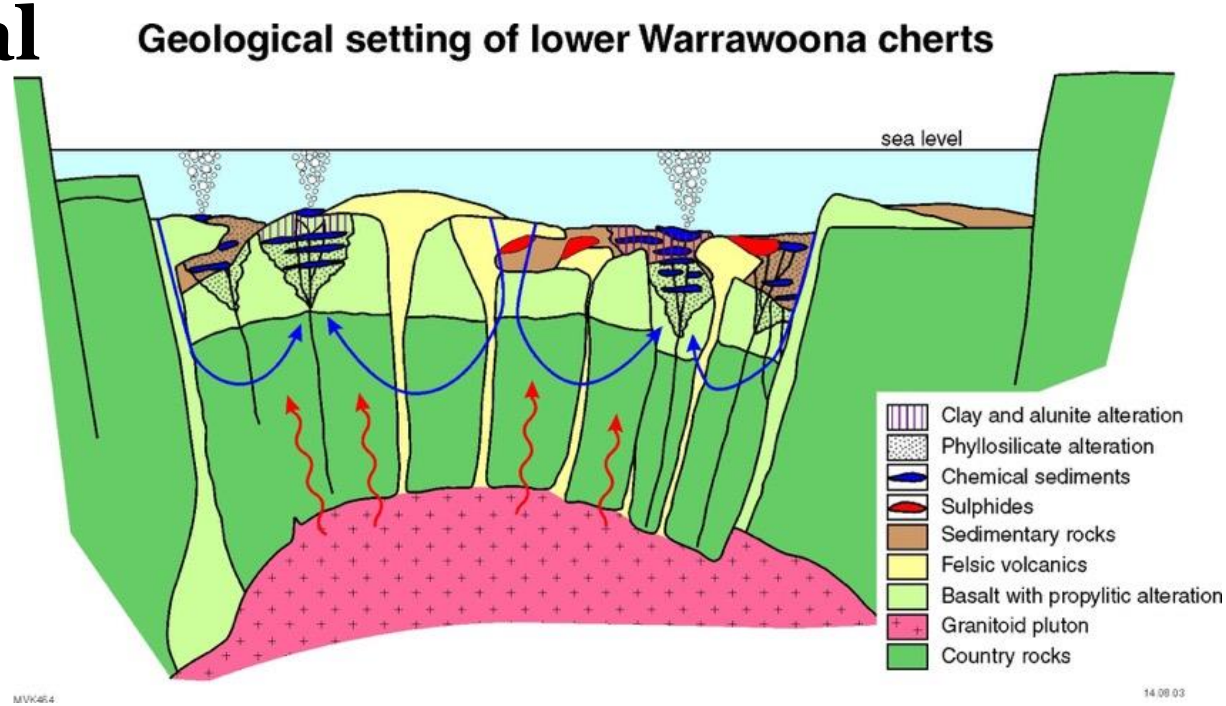
(adapted from Des Marais et al., 2008)

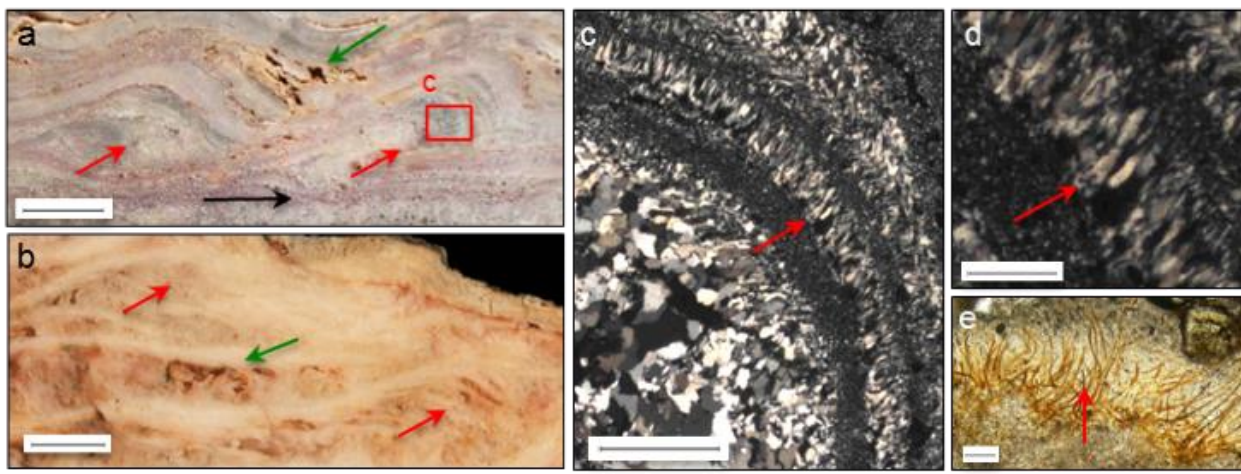
I. Hydrothermal Spring Systems

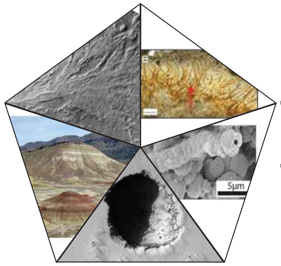
Description:

Where heat is transported convectively from hotter interiors (e.g., via volcanism or large impact) encounters water as it passes through rocky crusts.

For this study, discussion focused wherever these fluids intersected the surface.







I. Hydrothermal Spring Systems

Habitability

- Pros
  - Intrinsic to rocky planet crusts (geothermal, impacts)
  - Provide water, energy, nutrients & range of habitable conditions (pH, temperature, redox rx)
  - Springs sustain anoxygenic photosynthesis & chemotrophs
- Cons
  - Some systems short-lived & geographically restricted
  - Occasional toxicity (metals, high sulfide levels)

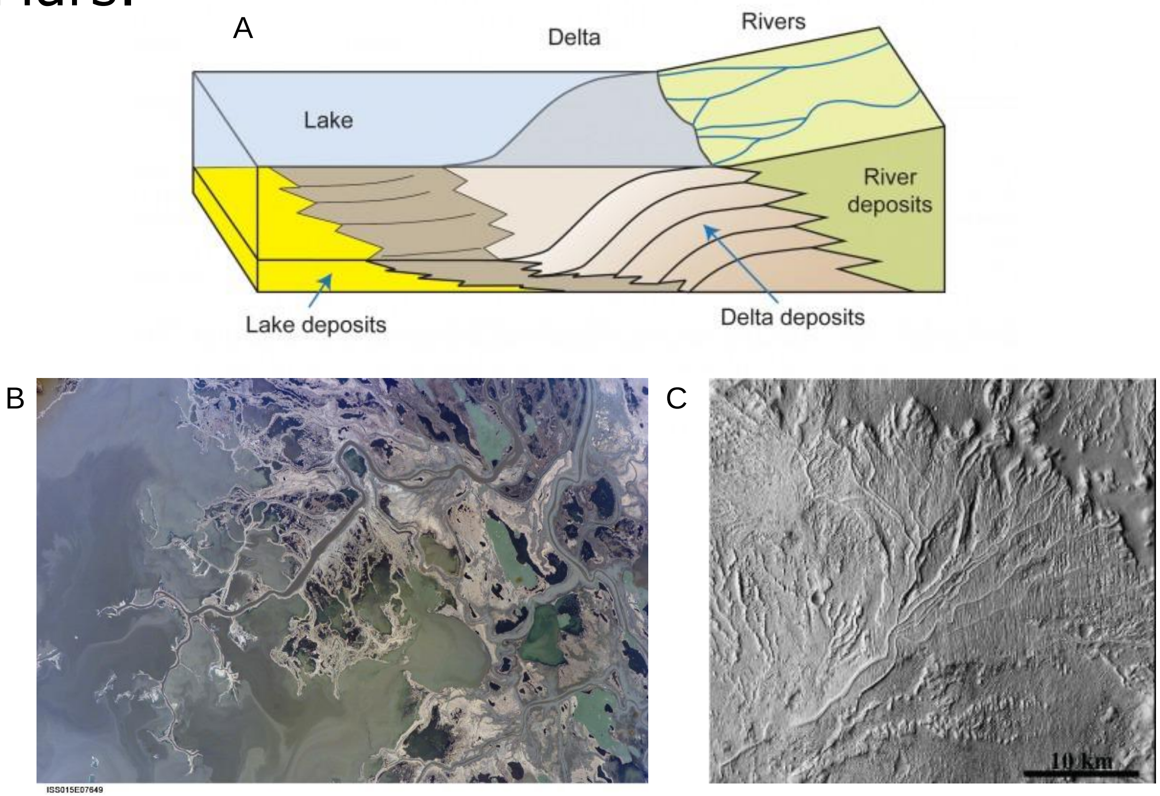
Biosignature Preservation

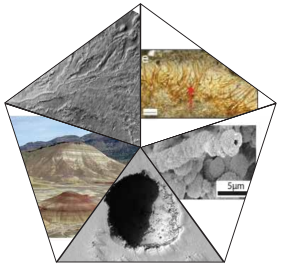
- Pros
  - Enhanced by abundant mineral precipitation (e.g., SiO_2, $CaCO_3$, FeO_x, $BaSO_4$)
  - Preserve cells, biofabrics, organics
  - Subaqueous conditions are favorable for preservation
- Cons
  - Subaerial conditions oxidizing (bad for organics, fabrics OK)
  - Subsurface environments less characterized, need studies

II. Subaqueous Environments

Description:

Subaqueous environments discussed here include deltaic and perennial lake systems (open and closed systems) as well as transient lake and playa systems, although many of the concepts apply to shallow oceanic environments as well, which may have existed on Mars.





II. Subaqueous Environments

Habitability

- Pros
  - Support highly productive microbial ecosystems
  - UV radiation shield
  - Can host a diversity of energy resources (e.g. hydrothermal vents, brine seeps, etc.)
- Cons
  - Fluvial input (a key nutrient source) is subject to seasonal and long term climatic variation
  - Large temperature and chemical fluctuations can negatively impact productivity

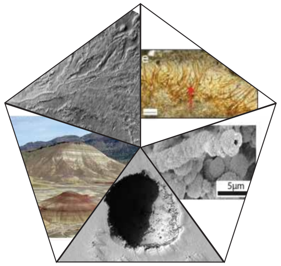
Biosignature Preservation

- Pros
  - Preserves organics, cells, biofabrics, fluid inclusions, and mineral and isotopic biomarkers
  - Subaqueous environment conducive to preservation (rapid burial and/or reducing environment)
- Cons
  - Preservation in "high energy" deltaic systems possibly compromised by oxidizing conditions
  - Timing of depositional layers difficult to determine from orbit

III. Subaerial Environments

Description:

Sub-aerial environments includes all environments at the surface or in the near-surface not covered by a body of water, but where water is derived directly from precipitation, snow melt, or ambient-temperature groundwater. Thus, this diverse suite of environments includes soils, wetlands, and cold springs, as well as glaciers and snow packs.



III. Subaerial Environments

Habitability

- Pros
  - Support a variety of metabolisms at the surface and in the sub-surface
  - Surface-atmosphere interface creates redox gradient energy sources
  - Can be regionally extensive
  - Subsurface provides UV radiation shield
- Cons
  - Strongly affected by climate change
  - Large range in productivity depending on environment

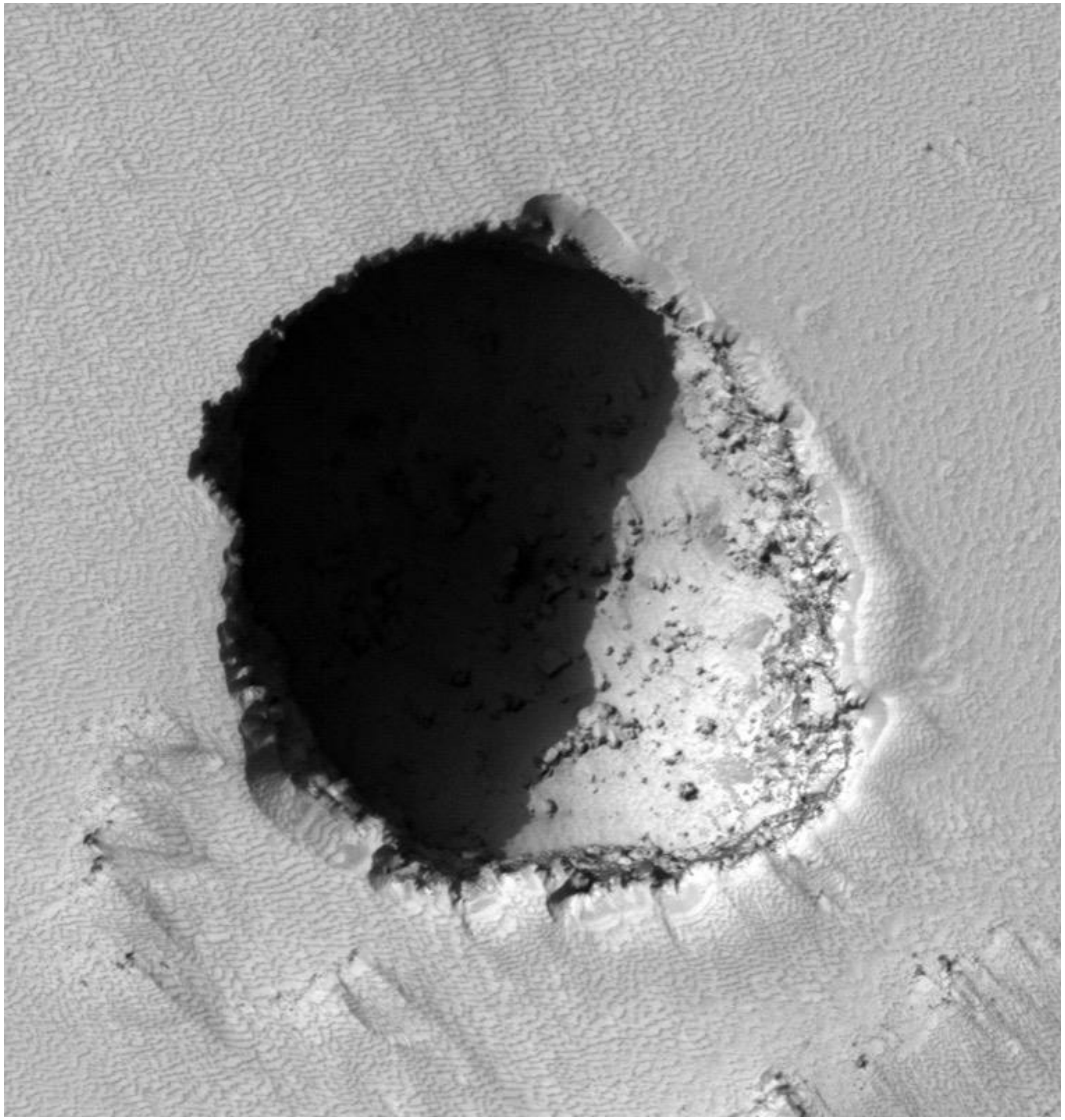
Biosignature Preservation

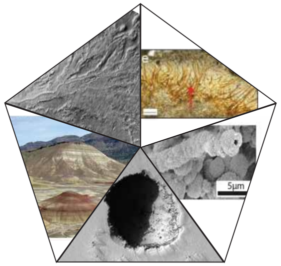
- Pros
  - All preserve organics; springs preserve textural + morphological biosignatures
  - Wetlands and springs support high biomass
  - Soils, springs, and wetlands often occur together; diversity allows many different preservation mechanisms
- Cons
  - Soils: organic preservation requires reducing conditions; low biomass; organics are concentrated only at paleosurface
  - All require rapid burial for preservation

IV. Subsurface Environments

Description:

The subsurface is considered to include all environments beneath the active regolith, except for those directly impacted by hydrothermal circulation, including shallow aquifers with pore spaces filled with liquid water or ice, deeper igneous crust, deep sedimentary deposits, and caves.





IV. Subsurface Environments

Habitability

- Pros
  - Are protected from harsh surface conditions
  - Stable environments could have extended the window of habitability, perhaps to the present
  - Volumetrically largest environment on Mars
  - Can provide energy sources to support life
- Cons
  - Cell density may be low

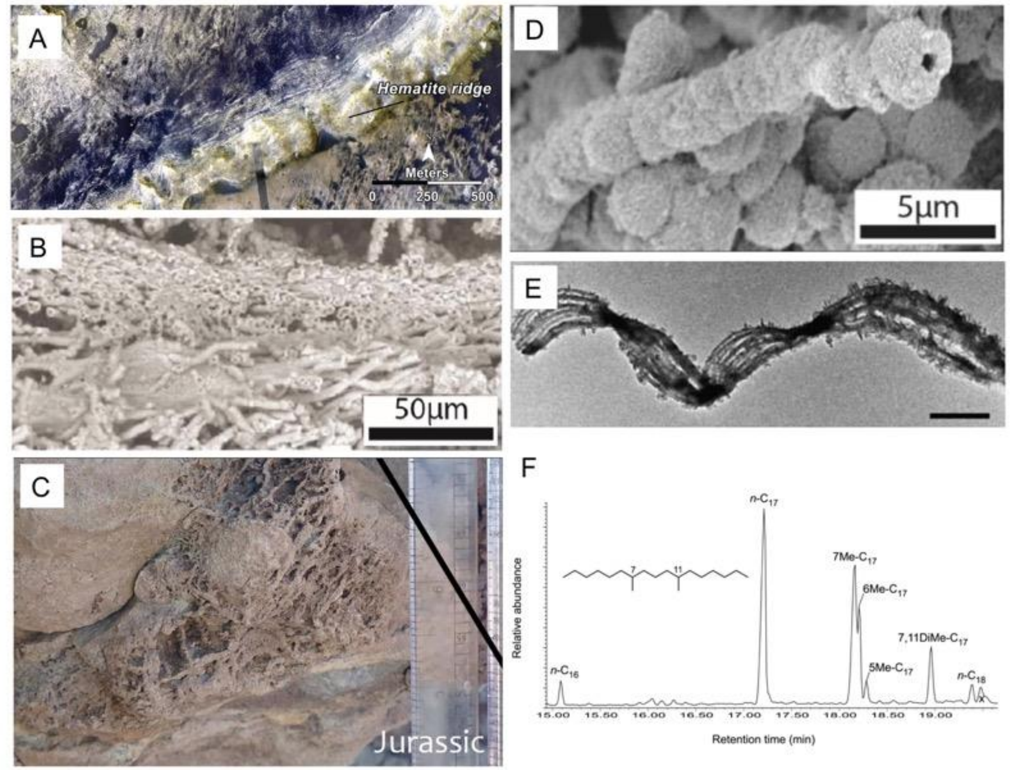
Biosignature Preservation

- Pros
  - Many types of biosignatures possible
  - Precipitation of secondary minerals leads to favorable environment for preservation
  - Conditions in subsurface likely reducing, making preservation of organic compounds likely
- Cons
  - Much remains to be learned about biosignatures in the subsurface

V. Iron-Rich Environments

Description:

Where circulating groundwater or hydrothermal systems mobilize iron to provide habitats high in dissolved iron. These iron-rich waters can be expressed as groundwater circulating through permeable rock, ferruginous marine and lacustrine settings, deep-sea hydrothermal vents and at the surface to form subaerial habitats, such as seeps and springs where iron oxides precipitate from the waters.



V. Iron-Rich Environments

Habitability

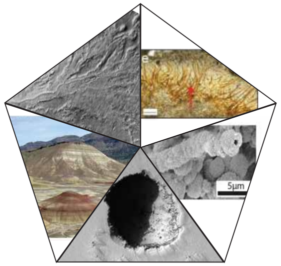
- Pros
  - Provides redox-active metal for microbial metabolism
  - Represent long-lived environments
  - UV radiation shield
- Cons
  - Primary TOC input is lower than in other systems
  - Acidity, if present, can limit microbial diversity

Biosignature Preservation

- Pros
  - Rapid entombment of cells is possible
  - Cellular remains can be preserved as lipid biomarkers
  - Organics sometimes preserved in iron oxides
- Cons
  - Organics may degrade in presence of: iron oxides, ionizing radiation

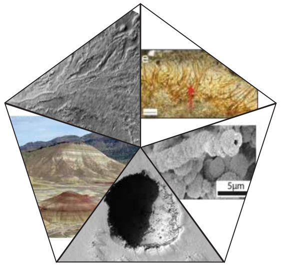
Exploring Past Habitable Environments on Mars: Environment Specific

NOTE: the following material only contains issues related to landing site selection. The complete considerations also include ground-based exploration and sample selection.



Environment-Specific Attributes Relevant to Orbital Observations

- **Hydrothermal**: Identifying the extent of these deposits and uniquely differentiating them from low-T deposits from orbital observations remains a significant challenge.
- **Subaqueous**: Unique identification of deltas (rather than fans into dry environments) and lake deposits is difficult from orbit.
- **Subaerial**: Paleosol deposits must be very thick to be identified from orbit, and cold spring deposits are localized and difficult to identify with resolutions currently available.
- **Subsurface**: It is difficult to uniquely differentiate units altered in the subsurface from surface units buried after surface alteration using orbital data alone.
- **Iron-rich**: Iron-rich environments can be identified on Mars with CRISM VNIR spectral data, but it is difficult or impossible to spectrally identify sulfides.



Environment-Specific Attributes relevant to Observations and Sample Selection on the Ground

- **Hydrothermal:** alteration zones and deposits from mineralogy, chemistry, and geomorphology; difficult to differentiate from leaching/low-T in some cases
- **Subaqueous:** lithology, texture and bed geometry; challenge is constraining age and duration
- **Subaerial:** paleosols/wetlands from visible horizons, morphologies, chemical profiles; spring morphologies and mineralogy; identification of environments is difficult without in situ measurements
- **Subsurface:** alteration zones and deposits from mineralogy, geochemistry, lithology; impact/ejecta or cave environments can be detected at far range; difficult to differentiate high-T from leaching/low-T in some cases
- **Iron-rich environments:** massive iron-rich oxides or iron oxide cementation

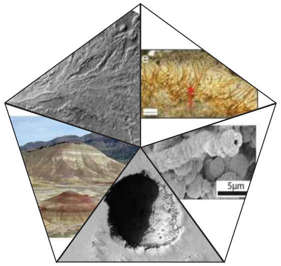
Exploring Past Habitable Environments on Mars:

Common Challenges

Strategies and Priorities

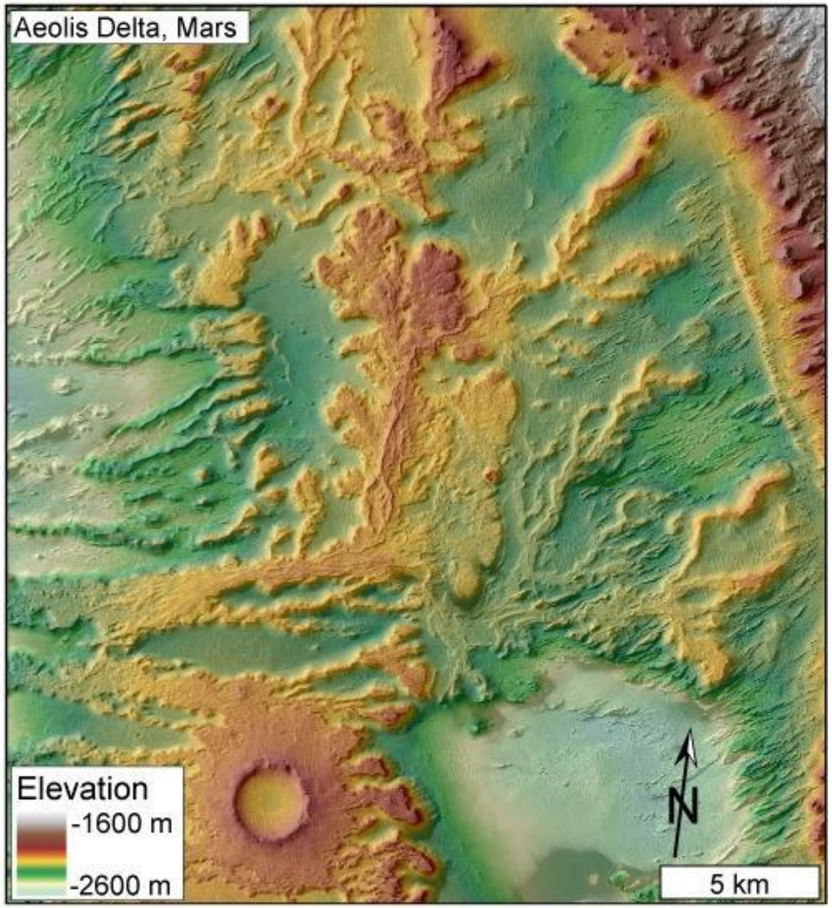
Urgent Needs and Future Research

NOTE: the following material only highlights issues related to landing site selection. The complete considerations also include ground-based exploration and sample selection.



Common Challenges

- The limit in resolution of our orbital assets potentially introduces a bias towards prioritizing environments that are more easily identified remotely, regardless of their potential for biosignature preservation.
- Orbital reconnaissance of many potential sites for exploration cannot provide a reliable indication of <u>how long an environment may have been habitable</u>.



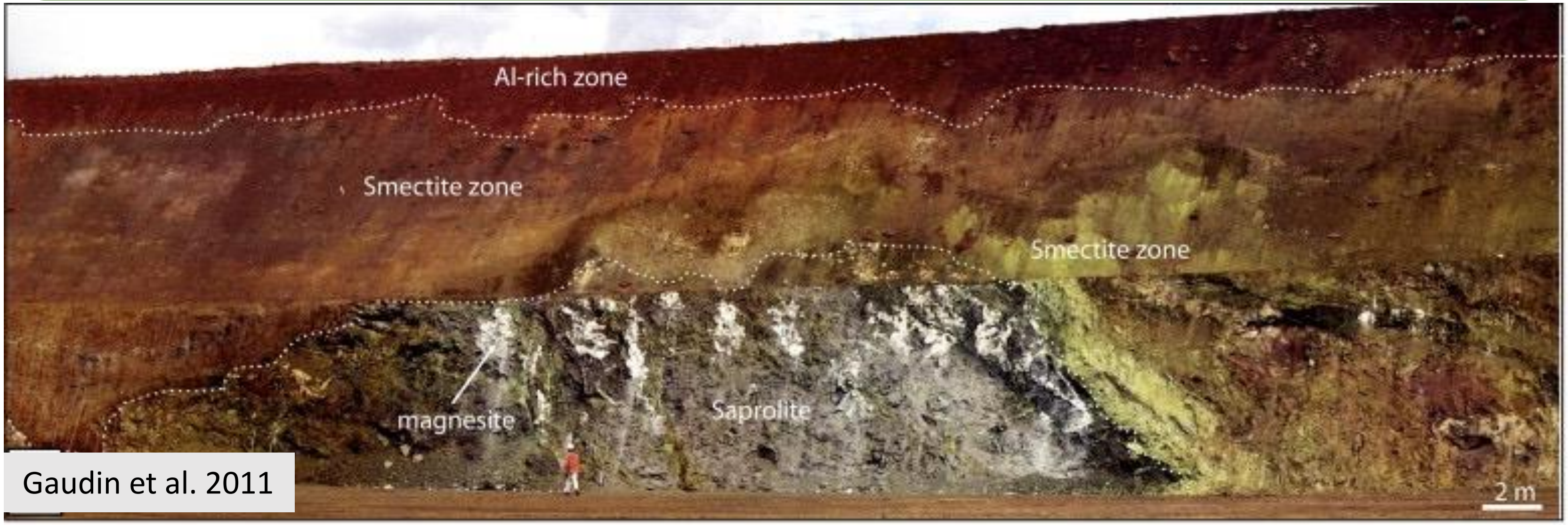
DiBiase et al. 2013

Common Challenges

- Fundamental mismatch in scale between what can been observed from orbit (e.g., on Mars) and what we have traditionally looked for on the ground.
- Spatial heterogeneity of the most promising deposits, which includes local, chemical or sedimentological variability.

Common Challenges

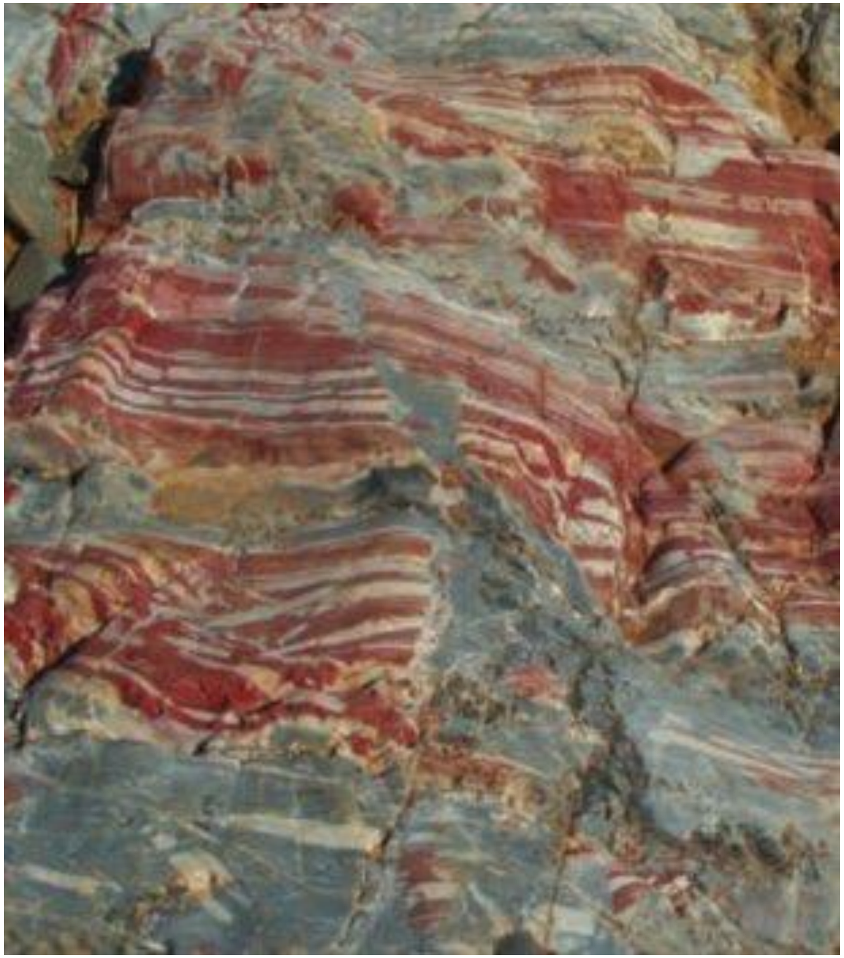
- Recognizing the particular features of a habitable environment in the absence of abundant life.
- Time Scales of a Deposit's History: Including how old a deposit is and how long a deposit has been exposed to the weathering and radiation environment on the surface of Mars.



Gaudin et al. 2011

Strategies and Priorities

1. Better understanding of the dichotomy between habitability and preservation.
2. Studies of temporally appropriate terrestrial analogs of early Mars. [Note: preservation from early Earth environments might have differed in important ways from preservation in similar early Mars environments]
3. The astrobiological exploration of Mars must be coordinated across a broad range of spatial and temporal scales.



Strategies and Priorities

4. A site that includes a variety of geologic records indicative of habitable environments would be most desirable.
5. Although organic biosignatures received considerable attention at the workshop, a consensus emerged that landed missions should also seek a diverse suite of potential biosignatures.

Strategies and Priorities

6. Missions should also seek environments on Mars where life conceivably might have originated, or where chemical reactions that could have spanned the prebiotic-biotic transition could have been present.
7. Investigations of certain analog environments (e.g., subaqueous settings, hydrothermal spring systems) are further advanced than investigations of others (e.g., subsurface), as is the state of the science of remote identification of these environments.

Urgent Needs and Future Research

- Two aspects of future mission development that would help astrobiological exploration were consistently highlighted in discussions:
  - Must improve spatial and spectral resolution of spectrometers and imagers on orbiters to support remote assessment of environments of interest.
  - Need to improve instrumentation on rovers that might detect and identify a diversity of potential *in situ* biosignatures. [Including designed to respond successfully to the unique complications of biosignature preservation on Mars].

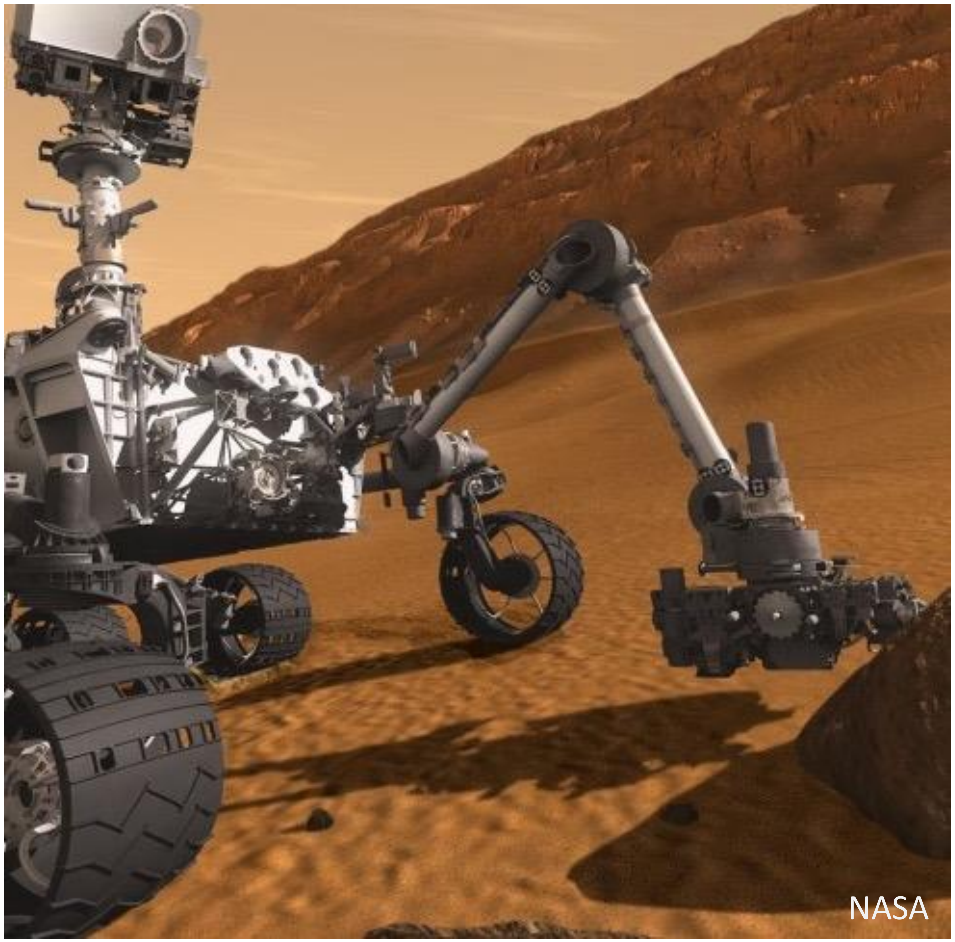
Urgent Needs and Future Research

- The conference discussions clearly indicated that the distinctions between "subsurface" and "near surface" environments should be delineated more clearly. Research to more effectively characterize exhumed geological deposits from past subsurface environments regarding their habitability and their potential to preserve biosignatures.
- Research to improve our ability to adapt our current understanding of terrestrial life to the astrobiological exploration of martian environments. E.g. what the biosignature signals might be if photosynthetic microorganisms had not evolved, and instead the environments were only inhabited by chemosynthetic microorganisms.

Urgent Needs and Future Research

- Investigate how martian systems and environments might be chemically or physically different from Earth environments and might produce, preserve or destroy biosignatures at different rates or in different proportions than expected from terrestrial analogs.
- Strategies to search for past life on Mars are also relevant to the search for extant life. E.g. a campaign to identify potential biosignatures at sites that were habitable in geologically recent times could demonstrate that life persists elsewhere on Mars.

Urgent Needs and Future Research



- Need better understanding of how well instruments selected for Mars-2020 can separate the biotic signal from the abiotic background noise in different environments.